AD NUMBER
AD500112
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TO: unclassified
FROM: confidential
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AD500112

DMIC Report S-20
April 4, 1968
DG.I-CC2312-006

MATERIALS FOR SMALL-ARMS GUN BARRELS (U)

DEFENSE METALS INFORMATION CENTER
Battelle Memorial Institute
Columbus, Ohio 43201

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1. To collect, store, and disseminate technical information on the current status of research and development of the above materials.

2. To supplement established Service activities in providing technical advisory services to producers, melters, and fabricators of the above materials, and to designers and fabricators of military equipment containing these materials.

3. To assist the Government agencies and their contractors in developing technical data required for preparation of specifications for the above materials.

4. On assignment, to conduct surveys, or laboratory research investigations, mainly of a short-range nature, as required, to ascertain causes of troubles encountered by fabricators, or to fill minor gaps in established research programs.

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Roger J. Runck

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Director

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DMIC Report S-20
April 4, 1968

MATERIALS FOR SMALL-ARMS GUN BARRELS(U)

by

C. W. Marschall and H. J. Wagner

to

OFFICE OF THE DIRECTOR OF DEFENSE
RESEARCH AND ENGINEERING

[illegible]

GROUP-4
Downgraded at 3 year intervals
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DEFENSE METALS INFORMATION CENTER
Battelle Memorial Institute
Columbus, Ohio 43201

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MATERIALS FOR SMALL-ARMS GUN BARRELS (U)

C. W. Marschall and H. J. Wagner*

SUMMARY

(U) At the request of the U. S. Air Force, a survey was conducted by the Defense Metals Information Center on materials for small-arms gun barrels (up to approximately 30-mm-bore diameter). Particular emphasis was given to materials for weapons designed for high rates of fire.

(U) Currently, small-arms barrels are produced in the United States from Cr-Mo-V and Cr-Mo low alloy steels containing 0.40 to 0.55 percent carbon, quenched and tempered to a hardness of approximately Rockwell C 30, with a chromium-plated bore. In addition, a Stellite 21** liner (Co-Cr-Mo alloy) is added to the breech end of many rapid-fire barrels. The chromium plate and the Stellite liner help to combat erosion of the bore resulting from chemical reaction with the propellant gas, high velocity "scrubbing" by the gases and solid particles, and the high temperatures generated by firing. With this type of protection against bore erosion, which is the main problem in high rate-of-fire weapons, a gun barrel may last indefinitely (>100,000 rounds) if the firing rate is sufficiently low or if sufficient time is allowed between short bursts of rapid-fire. Even with the plating and the liner, however, severe firing schedules can quickly deteriorate the bore surface sufficiently to render the barrel useless. For example, continuous firing at a rate of 20 rounds per second, a typical rate for many machine guns, will cause a weapon to stop functioning after only a few hundred rounds have been fired.

(U) With the advent of weapons systems designed to fire hypervelocity projectiles at high firing rates for sustained time periods, serious problems arise with regard to barrel lifetimes. These problems are being attacked on several fronts which include development of:

(1) Propellants with lower flame temperatures

(2) Propellant additives that carry away heat or coat the bore (also called boundary layer cooling)

(3) Deterrent coatings on the propellant grains to modify burning

(4) External cooling of the barrel

(5) Improved barrel materials.

This report is concerned with the last approach listed above: namely, the development of improved barrel materials.

(U) Chromium plated bores and Stellite liners were developments of research conducted during World War II. Between 1946 and 1960, extensive efforts were made to improve barrel lifetimes further. Studies included barrel materials, liner materials, and surface treatments. Among the liner materials studied were alloy steels, cobalt-base alloys, chromium-base alloys, nickel-base alloys, iron-aluminum alloys, molybdenum alloys, columbium-base alloys, ceramics, and cermets. Performance of a particular liner material was evaluated by comparing it with a standard Stellite 21 liner. In the majority of cases, the candidate materials were found to be inferior to Stellite. However, some of the liner materials with very high melting points (such as molybdenum alloys) did appear to be markedly less susceptible to erosion than the standard Stellite 21; with these relatively brittle materials, barrel lifetimes were limited by cracking and spalling of the liner, rather than by erosion. Many attempts were made, particularly with molybdenum, to overcome this brittleness problem by alloying, design improvements, and improved fabrication procedures, and, although the efforts met with some success, the magnitude of the improvement was not sufficient to warrant a changeover from the Stellite liner. In the late 1950's, studies on columbium-alloy liners gave very encouraging results, particularly in combination with a newly developed procedure for making thin, full-length liners. It was demonstrated that full-length columbium liners extended barrel lifetimes far beyond those possible with either Stellite 21 or molybdenum partial-length liners.

(U) In the early 1960's, interest waned in attempts to improve the performance of small-arms barrels, possibly because of the rapid developments being made in missiles and rockets. Consequently, little research and development was conducted in this period. However, when the United States became deeply involved in the Vietnam conflict, interest in small arms again quickened and a number of research and development programs have been initiated. These are aimed primarily toward development of full-length refractory-metal liners inside steel barrels. Various refractory metals and alloys as well as a number of processing procedures (including coextrusion and high-energy-rate forming) are under investigation. At the time of preparation of this report only preliminary results of these efforts are available.

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**Stellite 21 is a commonly used name for the trade-marked alloy, Haynes Stellite alloy 21.

INTRODUCTION

(U) The United States Air Force is currently undertaking a coordinated effort to improve the performance of small arms from the standpoint of materials, propellants, design, and fire-control systems. The objective is to increase barrel lifetimes while simultaneously increasing the muzzle velocity and the rate of fire. The need for this effort is based upon experience with rapid-firing weapons, such as the Mini-gun, currently in use in Vietnam. In order to realize reasonable barrel lifetimes, these weapons must be fired according to fairly moderate schedules, a typical firing schedule might consist of 3-to-5 second bursts, with 20-to-30 second cooling intervals between bursts and longer cooling periods after a certain number of bursts have been fired(1).* If the burst time is increased to 15 seconds, the barrel lifetime is reduced drastically and the weapon quickly becomes useless. In combat situations, it is not difficult to imagine circumstances in which it would be highly desirable to be able to continue firing for more than 3-to-5 seconds.

(U) In order to plan and execute research and development programs aimed at improving barrel lifetimes in high-rate-of-fire weapons, the Air Force required information on the current state of the art, results of prior research and development programs, and the efforts currently being undertaken by other organizations. A request was made to the Defense Metals Information Center in the fall of 1967 to prepare a report that would provide such information. This report has been prepared in response to that request.

(U) This report is intended to give an up-to-date, accurate assessment of materials currently in use for small-arms gun barrels and the efforts under way to improve barrel lifetime through advanced materials technology. Depth of analysis is limited, however, due to the short time available for preparation of the report. A brief review is included on the numerous research and development efforts on gun barrel materials that took place between 1941 and 1960. This review is based largely upon References (2), (3), and (4), which in turn, were based upon numerous company reports and Government-laboratory reports. Because of time limitations, no attempt was made to analyze each of the original sources. The basic references are available through the Defense Documentation Center in Alexandria, Virginia, and cover the following time periods:

Time Period	References
1941-1945	(2) National Defense Research Committee, "Hypervelocity Guns and the Control of Gun Erosion", Washington, D.C., 1946.
1946-1955	(3) Cohn, G., "Barrels for Automatic Weapons", Franklin Institute Report FA 2251, 1959. (Confidential)
1956-1960	(4) Cohn, G., "Barrels for Automatic Weapons", Franklin Institute Report FA-2461, May, 1961. (Confidential)

As a convenience to the reader, complete Tables of Contents of the above three references are included in Appendix A of this report.

*Numbers in parentheses pertain to references, which are listed on page 10.

(U) Beginning in 1960, research into materials for gun barrels was reduced drastically, apparently because of rapid developments in missiles and rockets and the possibility that conventional small arms might become obsolete. Accordingly, there are few reports available on this subject since 1960, even though a number of new projects have been initiated within the past several years. Several of these recent projects are described in this report, but, at the time of preparation of this report, few results are available.

TERMINOLOGY, DEFINITIONS, AND BACKGROUND INFORMATION (U)

(U) Because many persons involved with materials research and development may not be familiar with small-arms gun barrels, this section is included to clarify terminology and to provide background information.

Regions of a Gun Barrel (U)

(U) A cross section of a typical gun barrel is shown schematically in Figure 1. Four regions are shown: the breech, through which the round is loaded, the chamber, which holds the round before firing, the bore, through which the projectile travels when the round is fired, and the muzzle, from which the projectile emerges.

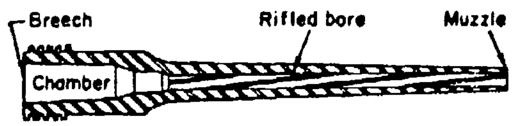

FIGURE 1. SCHEMATIC CROSS SECTION OF A GUN BARREL(5) (U)

(U) When liners are used to prolong barrel lifetime, a quasi two-piece tube may be used, as illustrated in Figure 2.(5) The two pieces are: (a) a cap, containing the chamber, and (b) a lined tube. Since the hottest region of the tube is near the forward end of the liner, the gap between the tube and the cap reduces the heat flow to the cap, thereby keeping the chamber comparatively cool. This limits thermal expansion and helps maintain proper clearance between chamber and cartridge case; at the same time, the likelihood of cook-off* is minimized.

Rifling (U)

(U) Rifling refers to the spiral grooves in the bore of a barrel that are designed to impart spin to a projectile for greater accuracy and carrying power. The rifling may have a uniform twist throughout the barrel length or it may begin with zero twist at the breech end and gradually increase in twist for a certain distance and remain constant thereafter. The latter type of rifling, frequently referred to as gain-twist rifling, is said to reduce wear at the origin of rifling.

(U) Rifling lands and grooves are illustrated in Figure 3. Although the actual rifling dimensions are determined from the dynamics of the projectile, approximate dimensions are:

*In the context of this report, cook-off is the premature detonation of the ammunition, that is, before it has been struck by the firing pin, as a result of overheating of the chamber.

groove depth $\approx \frac{1}{100}$. bore diameter

number of grooves $\approx$ 8 times the bore diameter in inches

$\frac{\text{groove width}}{\text{land width}} \approx \frac{3}{2}$

In Figure 3, the lands and grooves shown are sharply rectangular, however, they may have other shapes, without sharp corners.

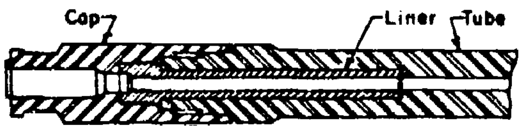

FIGURE 2. QUASI TWO-PIECE TUBE WITH LINER(5) (U)

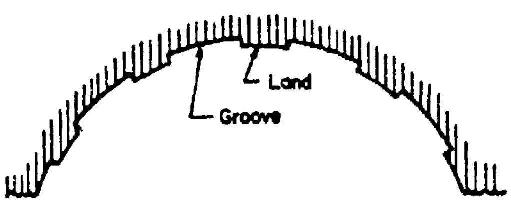

FIGURE 3. RIFLING LANDS AND GROOVES (U)

Definitions (U)

(U) Caliber - the diameter of a gun tube bore. The present trend for small arms is to express the bore diameter in millimeters, rather than in decimal inches.

(U) Small arms - guns having a caliber up to about 30 mm.

(U) Hypervelocity weapons - weapons that fire a projectile at a muzzle velocity in excess of approximately 3500 feet per second.

(U) Rotating band - soft metal band around a projectile near its base; it ensures a tight fit in the bore by engaging the rifling and gives spin to the projectile.

(U) Engraving - process by which rotating bands are cut by the rifling.

Tube Pressure and Projectile Velocity (U)

(U) A gun barrel is basically a tubular pressure vessel with an opening at the muzzle end. When a round is detonated in the chamber, hot gases are produced, thereby causing a rapid pressure rise behind the projectile. The projectile is thus accelerated down the barrel. Despite the increased volume occupied by the entrapped gases as the projectile moves out of the chamber, the pressure continues to rise because of continued burning of the propellant. Eventually, as the expansion continues and the propellant is consumed, the pressure reaches a maximum value and declines gradually thereafter. The velocity of the projectile increases continuously as it travels through the tube, however, the rate of increase drops when the pressure begins its decline. Typical curves of chamber pressure and projectile velocity as functions of both time and position are shown in Figure 4 for a .30-caliber gun(5).

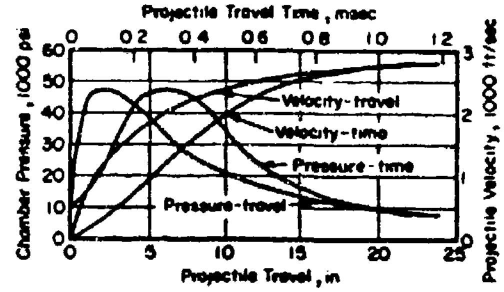

FIGURE 4. CHAMBER PRESSURE AND PROJECTILE VELOCITY IN A .30-CALIBER GUN(5) (U)

Temperatures Encountered in Gun Tubes (U)

(U) An appreciable amount of heat is released as the propellant is burned. Much of this heat is absorbed by the barrel of the gun. Naturally, the bore surface, being adjacent to the propellant gases, will reach higher temperatures than the exterior surface.

(U) The temperatures and temperature gradients encountered in gun tubes depend markedly on the firing schedule, i.e., the rate of fire and the duration of fire. For example, firing a single round will give rise to a momentary high temperature at the bore surface without affecting the temperature at the outer surface. At the other extreme, prolonged firing at a high rate can lead to melting of the barrel. Firing schedules intermediate to those described above will lead to intermediate temperatures and temperature gradients. A .30-caliber machine gun, for example, firing bursts of 125 rounds each in 14 seconds at a rate of one burst per minute, will reach essentially a steady state condition after 7 bursts have been fired. The maximum temperature at the bore surface will be approximately 2000 F, whereas the maximum temperature at the outer surface will be approximately 1400 F(5).

(U) The curves shown in Figures 5 and 6 indicate the temperatures encountered at various locations through the tube wall, as measured with thermocouples.(6,7) The bore surface is seen to be exposed to much more severe thermal cycling than any other region of the tube.

Evaluating Barrel Lifetimes (U)

(U) Barrel lifetimes are evaluated by conducting firing tests. A barrel is said to have a "velocity life" and an "accuracy life". Velocity life refers to the number of rounds fired before the projectile velocity decreases by a certain percentage (usually 6 percent; often, however, simply 200 feet per second), compared with the velocity measured at the start of firing. Accuracy life refers to the number of rounds fired before the projectile yaw exceeds approximately 15 degrees.

Properties Needed by Barrel Materials (U)

(U) To function satisfactorily, gun barrel materials must have the following properties:

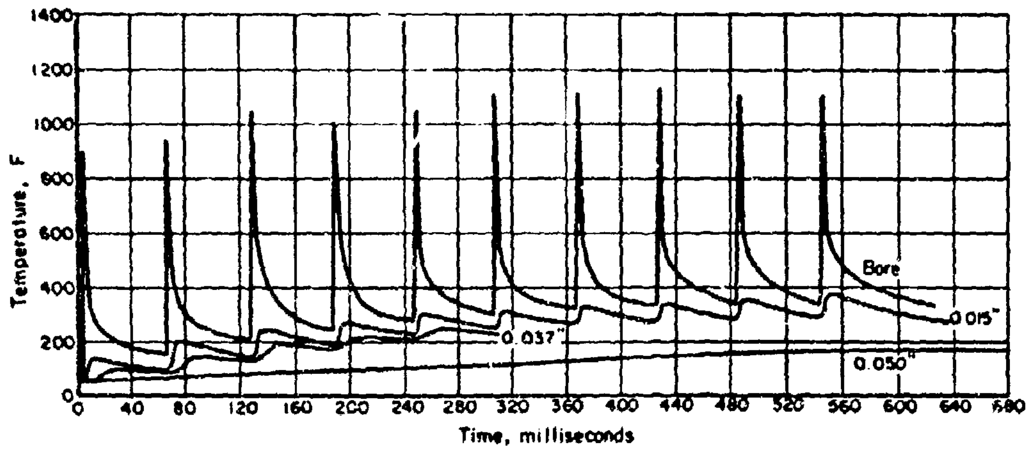

FIGURE 5. TEMPERATURES MEASURED WITH THERMOCOUPLES AT A DISTANCE OF 20 INCHES FROM THE BREECH DURING FIRING OF A .50-CALIBER MACHINE GUN(6) (U)

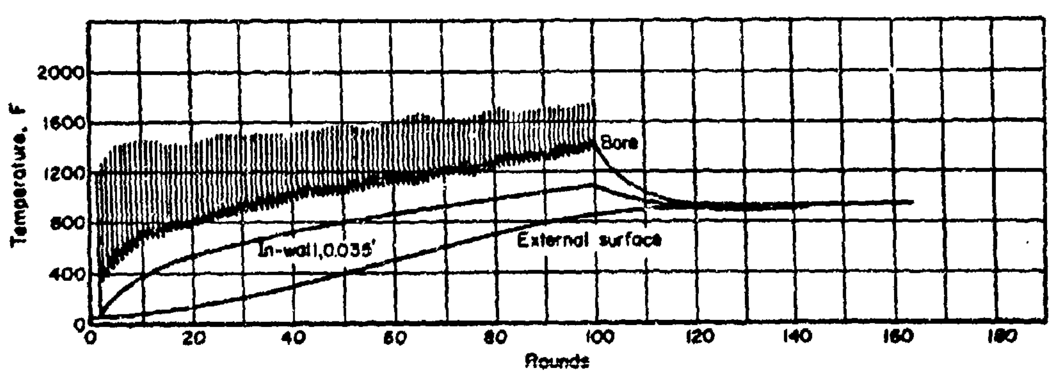

FIGURE 6. TEMPERATURES MEASURED WITH THERMOCOUPLES AT A DISTANCE OF 5 INCHES FROM THE BREECH DURING FIRING OF A .50-CALIBER MACHINE GUN(7) (U)

(1) Strength at both low and high temperatures to carry the pressure load without permanent deformation

(2) Ductility or toughness at both low and high temperatures to endure shock loading (both mechanical and thermal)

(3) Hot hardness to withstand land swaging or flattening

(4) Wear resistance to withstand abrasion from high velocity gases and rotating bands

(5) High melting point

(6) Resistance to chemical attack by propellant gases

(7) Fabricability.

Other properties that must be taken into account in designing gun tubes include thermal conductivity, heat capacity, and thermal-expansion coefficient.

MATERIALS USED IN CURRENT PRODUCTION OF SMALL ARMS BARRELS (U)

(U) Many of the requirements described in the foregoing paragraph are met by heat-treatable low-alloy steels. Current military specifications for small-arms-barrel steels call for the following compositions:

Element	Chemical Composition, percent by weight		
	ORD 4150	ORD 4150 Resulfurized	Chrome-Moly-Vanadium
Carbon	0.48-0.55	0.47-0.55	0.41-0.49
Manganese	0.75-1.00	0.70-1.00	0.60-0.90
Phosphorus	0.040 max	0.040 max	0.040 max
Sulfur	0.040 max	0.05-0.09	0.040 max
Silicon	0.20-0.35	0.20-0.35	0.20-0.35
Chromium	0.80-1.10	0.80-1.15	0.80-1.15
Molybdenum	0.15-0.25	0.15-0.25	0.30-0.40
Vanadium	-	-	0.20-0.30

The complete Military Specification MIL-S-11595D (MR), dated January 3, 1966, entitled "Steel, Bars and Blanks (Under 2 inches in Diameter) for Barrels of Small Arms Weapons", is included in Appendix B of this report.

(U) The steels specified here perform well as long as firing schedules are not too severe. However, if excessively high barrel temperatures are generated by rapid firing for prolonged periods, several shortcomings of steel become apparent, of which bore erosion is the most serious. There are several consequences of such erosion: (1) the rifling becomes worn away, leading to improper spin of the projectile, and (2) the bore is enlarged, thereby decreasing accuracy and allowing the propellant gas to escape past the projectile, thus lowering the muzzle velocity.

(U) Erosion or enlargement of the bore is believed to stem primarily from three sources:

(1) Chemical - reaction of the bore with propellant gases, followed by removal of the reaction products; this exposes a fresh bore surface for the next wave of propellant gas and the cycle repeats itself

(2) Thermal - melting of a very thin layer of the bore surface, which is "washed out" with the escaping gases

(3) Mechanical - wear and abrasion from the sliding projectile.

Consequently, much attention has been devoted over the past 30 years to the development of bore surfaces that are superior to low alloy steels with respect to melting point, wear resistance at high temperature, and resistance to chemical attack. These attempts have taken several directions, as are discussed in a later section. However, only two developments have been found to give performance sufficiently superior to that of a simple steel barrel to warrant their use in current small arms manufacture. These are:

(1) Chromium plating of the bore surface

(2) Lining of the breech-end of the bore with Stellite 21* (a Co-Cr-Mo alloy).

Both were developed during World War II and were used in machine guns in the Pacific area toward the close of the war. Used in combination, chromium-plated bores and Stellite 21 liners increased the useful life of machine guns by a factor of 3 when firing short bursts and by a factor of 10 when firing long bursts. In the intervening years, the procedures employed in both plating and lining the bore have been optimized and studies have been conducted to find even better ways to minimize bore erosion. At the present time, no other materials, with the possible exception of columbium-lined steel barrels, have been demonstrated to be consistently superior to chromium-plated steel barrels with a Stellite 21 liner.

(U) Despite the great improvement in barrel lifetime offered by chromium plating and Stellite 21 liners, one should not assume that the erosion problem is solved. Even with these developments, a .60-caliber machine gun**, firing 50-round bursts at a rate of 20 rounds per second with 2-minute cooling intervals between bursts, will exhibit excessive velocity drop after only approximately 400 rounds.

APPROACHES BEING TAKEN TO ALLEVIATE BARREL-EROSION PROBLEMS (U)

(U) The barrel-erosion problem in weapons designed to fire hypervelocity projectiles at high rates of fire is closely related to the maximum temperatures developed at the bore surface and the ability of the barrel material to function properly at these temperatures. Various approaches toward alleviation of the bore-erosion problem are being undertaken concurrently, including development of methods to reduce bore temperatures and development of improved barrel materials. Methods that have been and are being studied to reduce bore temperatures include:

(1) Use of propellants with lower flame temperatures

(2) Use of propellant additives that carry away heat or coat the bore (also called boundary-layer cooling)

(3) Use of deterrent coatings on the propellant grains to modify burning

(4) External cooling of the barrel.

The first three of these methods are discussed in Reference 8. External cooling of the barrel, including water-cooled jackets and bonded-metal jackets of high thermal conductivity, are discussed in Reference 3. Attempts to improve barrel materials are discussed in subsequent sections of this report.

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*See footnote, page 1.

**A nonconventional size used for test purposes only.

REVIEW OF ATTEMPTS TO DEVELOP IMPROVED MATERIALS THROUGH 1960 (U)

(U) As indicated earlier, both chromium plating and Stellite lining of bores were developments of World War II. The improved performance accompanying these developments triggered interest in additional efforts to develop even better materials. Between 1946 and 1960, extensive efforts were undertaken to realize this goal. Included were studies on

(1) Barrel materials

(2) Liner materials

(3) Surface treatments.

These are reviewed briefly in the paragraphs following. The majority of this work was conducted by, or under the supervision of, Springfield Armory, Springfield, Massachusetts*, and is discussed in greater detail in References 3 and 4.

Barrel Materials (U)

(U) Throughout World War II, the standard barrel material was AISI 4150 steel, and, as already noted, this is still being used. However, other materials, including both ferrous and nonferrous types, have been investigated.

Alloy Steels

(U) Numerous alloy steels were studied in an attempt to find a barrel material superior to 4150 steel. Alloying elements studied included chromium, nickel, molybdenum, tungsten, and vanadium in various combinations and in amounts up to 30 percent. While some of the alloy steels showed promise, only one showed sufficient potential advantages to warrant further development. This was a Cr-Mo-V low-alloy steel. As noted earlier, this steel is currently used for small arms barrels, along with 4150 steel.

Titanium

(U) In the early 1950's, firing tests were performed on barrels made of

(1) Unalloyed titanium

(2) Ti-4 Ferrochrome

(3) Ti-4Al-4Mo

(4) Ti-3Al-5Cr.

Severe erosion was observed after one round. It was concluded that titanium had potential as a barrel material only when the bore could be fully protected from the propellant gases. Some efforts were made to use titanium barrels with molybdenum liners but these efforts were discontinued because of numerous difficulties with liner insertion.

Molybdenum

(U) In 1951, a .30-caliber breech section made of molybdenum was test fired to see if this material could withstand the explosive forces involved. As feared, the barrel burst into several pieces. No further work was done on molybdenum barrels.

Liner Materials (U)

(U) In the many efforts undertaken to develop improved liner materials during the period 1946 to 1960, the degree of success was judged by comparing the performance of the candidate material with that exhibited by Stellite 21. The various types of liner materials studied during this period included alloy steels, cobalt-base alloys, chromium-base alloys, nickel-base alloys, iron-aluminum alloys, molybdenum alloys, columbium-base alloys, ceramics, and cermets.

Alloy Steel Liners

(U) Several steels were tried as liners in standard steel machine gun barrels. Compositions are shown in Table 1.

TABLE 1. CHEMICAL COMPOSITION OF STEEL LINERS(a)

Steel	Composition, percent by weight(a)						
	C	Mn	Si	Cr	Ni	Mo	Ti
Timken 16-25-6	-	-	-	16	25	6	-
Silcrome XCR valve steel	0.45	-		24	4	[illegible]	-
Silcrome XB valve steel	0.76	-	2.9	19.5	13.5	-	
Nitrided [illegible] steel	0.[illegible]	0.[illegible]	0.[illegible]	-	-	-	[illegible]
Nitrided 2.40 Ti steel	0.05	1.00	0.69	-	-	-	[illegible].40

(a) Balance Fe.

In test-firings, the performance of each of these liner materials was inferior to that of Stellite 21 liners. The main fault of the nitrided steels containing titanium appeared to be excessive brittleness, leading to difficulties in machining and insertion, and in actual use, to premature velocity loss due to excessive cracking and chipping. Recommendations were made that additional experiments be conducted on titanium-bearing steels to develop greater ductility and machinability. Apparently, however, no additional work was undertaken on steel liners.

Cobalt-Base Alloy Liners

(U) Because of the success with Stellite 21 (a cobalt-base alloy) several other cobalt-base alloys were investigated as liner materials. Compositions of some of these alloys are shown in Table 2; the composition of Stellite 21 is included for comparison.

(U) Performance of the modified Stellites compared favorably with that of Stellite 21, although none of the three modifications was found to be superior to Stellite 21. For example, when firing on a 50-2 erosion schedule* in a .60-caliber barrel at a rate of 20 rounds per second, the velocity life, based on a 200-fps velocity drop, was:

Liner Material	Velocity Life, rounds
Stellite 21	400
Stellite Modification-Heat 1	315
Heat 2	330
Heat 3	390

(U) Cobalt-tungsten alloys, test fired under the same firing schedule as the Stellites, had an average velocity life of 225 rounds. It was therefore concluded that these alloys were inferior to Stellite.

(U) Alloy S-816 liners were evaluated in firing tests on both .50-caliber and .60-caliber machine guns, employing a CGL 350 schedule** and a 50-2 schedule, respectively. In a limited number of tests, S-816 was judged to be inferior to Stellite 21 in the .50-caliber barrel, but was considered to be a usable (though slightly inferior) substitute for Stellite 21 in the .60-caliber barrel.

(U) The remaining cobalt-base alloys listed in Table 2 were test fired in .60-caliber barrels and were found unsuitable as liner materials.

*Currently, the Springfield Armory is being closed, and its small-arms research group has moved to Rock Island Arsenal. The group is under the direction of Dr. A. Hammer.

*50-2 erosion schedule refers to 50-round bursts with 2-minute cooling intervals between bursts and complete cooling after 600 rounds.

**CGL 350 schedule consists of a 350-round burst followed by complete cooling; then five successive 500-round groups consisting of 100-round bursts at 2-minute intervals.

TABLE 2. CHEMICAL COMPOSITION OF COBALT-BASE ALLOY LINERS(U)

Alloy Designation	Composition, weight percent										
	Cr	Ni	Mo	Mn	W	Fe	C	Si	N	Other	Co
Stellite 21	29	2.5	5.5	1.0	-	2.5	0.28	1.0	-	-	Bal
Modified Stellite Heat 1	20	-	-	0.5	9.7	0.8	0.12	0.4	-	-	Bal
Modified Stellite Heat 2	20	-	-	0.5	14.0	1.2	0.11	0.4	-	-	Bal
Modified Stellite Heat 3	20	-	5.0	0.5	-	0.5	0.12	0.3	-	-	Bal
75Co-25W	-	-	-	-	25	-	-	-	-	-	75
S-816	20	20	4	0.5	4	4	0.4	0.5	-	4Cb	Bal
Haynes Alloys Heat 53-15	22.69	13.56	-	0.4	10.77	2.75	0.36	0.47	0.03	-	Bal
53-16	22.76	13.64	-	0.4	11.02	2.85	0.38	0.35	0.03	-	Bal
L251	18.0	10.0	-	-	14.0	-	-	-	-	-	Bal
L605	20.42	10.16	-	1.7	15.31	1.62	0.08	0.50	-	-	Bal
501	33.62	5.90	2.5	0.6	7.76	2.15	0.18	0.72	0.10	-	Bal
503	30.56	6.48	2.1	0.6	7.65	1.70	0.17	0.53	0.13	-	Bal
512-A	31.50	6.72	2.5	0.4	7.97	2.13	0.13	0.14	-	-	Bal
514-A	29.94	6.60	2.4	0.4	13.08	2.18	0.20	0.82	-	-	Bal

Chromium-Base-Alloy Liners

(U) Interest in chromium-base-alloy liners began early in World War II. A survey of various binary and ternary systems conducted at that time indicated that Cr-Fe alloys containing refractory metals (tungsten, molybdenum, tantalum) appeared promising with regard to strength, ductility and resistance to thermal shock. Several Cr-Fe alloys, possessing high melting points and excellent corrosion and erosion resistance to propellant gases, were prepared and evaluated as liners. These alloys included:

60Cr-15Mo-25Fe
50Cr-5Mo-45Fe
60Cr-10Mo-30Fe
50Cr-3W-47Fe-0.6N
50Cr-3W-46Fe (Vacuum melted and cast).

(U) Several 60Cr-15Mo-25Fe liners were test fired in .60-caliber barrels on a 50-2 erosion schedule. On the basis of velocity life, they were slightly superior to Stellite 21 (430 rounds versus 400 rounds, based on 200-fps velocity drop). However, they were only fair on the basis of yaw. It was concluded that these liners resisted wear very well but were susceptible to cracking.

(U) Liners of 50Cr-5Mo-45Fe and 60Cr-10Mo-30Fe were also test fired under the conditions described above. The performance of the 50Cr-5Mo-45Fe liners was similar, although slightly inferior, to that of the 60Cr-15Mo-25Fe liners; barrel life was limited by excessive yaw rather than by velocity drop. Evaluation of the relative merits of the 60Cr-10Mo-30Fe liners was not attempted because the barrels had been chromium plated ahead of the liner.

(U) Based on the successful performance of cast Stellite liners in machine guns, it was felt that if a chromium-base alloy could be developed with about 4 to 6 percent tensile elongation, it should not crack during firing. A 50Cr-3W-47Fe-0.6N alloy was developed that, in many cases, exhibited some ductility. However, despite intensive studies on effects of varying deoxidation practice and hot-working practice, a consistently ductile material could not be produced. Three barrels fired on a 50-2 erosion schedule failed after 300, 250, and 264 rounds; examination revealed severe cracking and erosion.

(U) The conclusion drawn from this work was that chromium-base alloys are promising liner materials from the standpoint of erosion resistance but are too susceptible to cracking. If sufficient ductility could be developed without sacrificing other desirable properties, chromium-base alloy liners would probably represent a significant improvement over Stellite 21 liners.

Nickel-Base-Alloy Liners

(U) Early studies involving firing tests of nickel and nickel-alloy liners demonstrated that these materials were very susceptible to intergranular attack by the propellant gases, unless properly alloyed with chromium.

(U) Compositions of some of the chromium-containing nickel-base alloys investigated are shown in Table 3. Test firing of Inconel X gave results inferior to those for Stellite 21; the lands were worn heavily and there was evidence of intergranular attack of the liner. The performance of Nimonic 90 was likewise unsatisfactory; much of the bore surface showed intergranular checking and corrosion, as well as wear and smearing.

TABLE 3. CHEMICAL COMPOSITION OF NICKEL-BASE ALLOY LINERS[a] (U)

Material	Cr	Mo	Mn	W	Fe	C	Si	Cb	Al	Ti	Other
Inconel X	14.7	–	0.55	–	6.75	0.05	0.40	1.08	0.71	2.38	–
Nimonic 90	20.7	–	0.70	–	0.93	0.06	1.29	–	0.32	3.48	21.1 Co
Hastelloy C (Modified)	8.0	22.5	0.5	2.0	5.2	0.1	0.5	0.9	–	–	–
Haynes AD-9	22.0	6.5	0.75	1.0	25.0	0.25	0.6	1.5	2.5	1.5	0.1B

(a) Balance Ni

(U) Testing of liners of modified Hastelloy C led to the conclusion that this material was not sufficiently durable.

(U) A Haynes AD-9 liner was test fired in a .60-caliber barrel. After only 150 rounds of the 50-2 erosion schedule, the velocity drop exceeded 200 fps and the liner was found to be cracked.

(U) Based upon these results, nickel-base alloys have not been considered strong candidates for erosion-resistant liners.

Iron-Aluminum-Alloy Liners.

(U) Two iron-aluminum-alloy liners were test-fired in .50-caliber barrels with the CGL-350 schedule. Alloy compositions were:

Fe-6Al-1Cb
Fe-8Al-1Ti

For both materials, the liner was "washed" into the bore after only 200 to 300 rounds had been fired. It was concluded that these alloys are unsuitable for use as liners.

Molybdenum and Molybdenum-Alloy Liners.

Of the various metals and alloys considered for use as barrel liners, probably none has received more attention than molybdenum. Its outstanding characteristics appear to be its high melting point (molybdenum melts at 2600 C, compared with 1450 C for gun steel and 1250-1300 C for Stellite 21) and its resistance to attack by hot propellant gases. In early tests on unalloyed molybdenum, it was found to be too soft at high temperatures to resist the engraving stresses and, hence, the lands were quickly flattened. Alloying with 0.1 to 0.2 percent cobalt increased the hot hardness of molybdenum sufficiently to overcome this problem.

(U) Another problem, that of brittleness, was not so easily overcome. Molybdenum undergoes a ductility transition as its temperature is changed. At low temperatures (including room temperature), molybdenum, unless extremely pure, is very brittle under tensile loading, whereas at elevated temperatures it exhibits appreciable tensile ductility. When a gun is fired, steep temperature gradients occur at the bore surface, giving rise to compressive stresses in the hot surface layers as they try to expand against the restraint imposed by the underlying, relatively cool layers. If the thermal stress is great enough, the hot layers will deform plastically. Upon cooling, the surface layers will have to stretch to return to their original dimensions, i.e., they will be stressed in tension. Tension stresses in molybdenum at temperatures below the ductile-brittle transition frequently lead to fracture. This, in fact, has proved to be the major problem in molybdenum liners. After firing, cracks are frequently found in the liners; this leads to the possibility of loosened particles jamming the bore or allowing the propellant gases to leak through to the underlying steel with consequent erosion. This susceptibility to brittle cracking is particularly dangerous in a weapon because the extent of damage cannot be predicted with confidence[9].

(U) Many efforts were made to overcome this brittleness problem, because it was known that molybdenum was superior to Stellite 21 with respect to erosion resistance. Attempts were made to improve the ductility of the liners by alloying and by developing better mechanical-working schedules and stress-relief treatments. In addition, attempts were made to take advantage of the directional properties associated with heavily-worked molybdenum. Other approaches included use of (1) segmented molybdenum liners of various designs (2) double liners, in which the molybdenum is encased in a material having an expansion coefficient midway between that of the molybdenum and that of steel, and (3) molybdenum liners made by power metallurgy methods. None of the efforts was successful in eliminating brittle cracking in molybdenum liners, even though it was demonstrated that, on the average, use of properly fabricated and designed molybdenum liners resulted in increased barrel lifetimes in comparison with those of Stellite 21 liners. Since 1957, little additional effort has been made to develop improved molybdenum liners. However, it is still viewed as a promising material for liners if a means can be found for lowering the ductile-brittle transition temperature sufficiently to eliminate the cracking problem.

Columbium-Base-Alloy Liners.

(U) The experience with molybdenum liners led to studies of other refractory metals. Columbium appeared particularly promising; its melting point was nearly as high as that of molybdenum and its ductile-brittle transition temperature was well below room temperature. In addition, its thermal-expansion coefficient's being considerably greater than that of molybdenum, reduced the thermal-expansion mismatch between the liner and the steel barrel.

(C) One problem with columbium appears to be insufficient hot hardness. Attempts to overcome this deficiency include alloying with tantalum or zirconium, cold-working and oxidation of the surface to produce interstitial hardening. Tests with partial-length liners have been encouraging. However, the most significant advance in refractory liners involves the development of thin-wall, full-length liners. Firing tests on barrels containing full-length columbium-liners of 0.025 to 0.030-inch wall thickness interstitially hardened, resulted in barrel lifetimes significantly greater than those obtained with Stellite liners or with molybdenum liners. For example, in .50-caliber barrels, firing 85 rounds per minute in 20-round bursts, the following barrel lifetimes were observed:

Liner	Barrel Lifetime, rounds
Stellite	1500
Molybdenum	2300
Columbium	3500

(U) Most of the work conducted on columbium liners took place in the late 1950's and the promising results appeared to warrant additional effort. However, as pointed out earlier in this report, interest in improving small arms waned in the early 1960's and it appears that no follow-up work was conducted, other than that which has recently been initiated.

Ceramic and Cermet Liners

(U) Various ceramic and cermet materials might be considered likely candidates as barrel liners because of their high melting points, high hot hardness, and, in many cases, resistance to reaction with propellant gases. However, as with molybdenum, it might be anticipated that brittleness would impose severe problems.

(U) It appears that little effort has been made to use such materials for gun liners. Reports of an attempt to use a short oxide-silicate liner in a .50-caliber barrel indicate that cracking occurred on the first round and complete fragmentation after 10 rounds. Similar results were obtained with a SiC-Ni cermet.

Surface Treatments

(U) Numerous attempts have been made to improve barrel performance by treating the bore surface to improve its hot hardness and its resistance to attack by the propellant gases. As already noted, chromium plating was found to be very effective in improving barrel lifetime. In combination with a Stellite 21 liner, it formed the standard for comparison when evaluating other methods for improving barrel lifetimes.

Nitriding

(U) Nitriding is a process whereby nitrogen is introduced into the surface of steel to impart a hard, wear-resistant surface.

(U) Tests on nitrided barrels indicate improvements over untreated barrels but not as great as those due to chromium plating. Using the two treatments together, i.e., chromium plating over a nitrided layer, has been demonstrated, in certain instances, to give better performance than chromium plating alone. However, the benefits of the nitriding prior to chromium plating apparently are not sufficient to warrant the additional operation. Consequently, current practice is to use the chromium plating alone.

Chromizing.

(U) Chromizing is a process in which a chromium-rich layer is formed on a steel surface. One procedure involves a displacement reaction in which chromium atoms from a chromium-iodide vapor replace iron atoms in the steel. Chromized steel has a number of characteristics that seem to be attractive from the standpoint of improving gun-barrel lifetime. These characteristics include: (1) resistance to oxidation and scaling at high temperatures, (2) good adherence to the base metal, and (3) good thermal-shock resistance.

(U) Although chromizing has been considered for use on bore surfaces, no reports have been located that would indicate that any firing tests have ever been conducted on chromized barrels.

Chromium-Iron-Alloy Plating.

(U) A process to electrodeposit various chromium-iron alloys received considerable attention as a means for improving the lifetime of steel barrels. Deposits studied included as little as 50 percent chromium to as much as 94 percent chromium. Despite some promising results, the procedure was not developed to the point where it equaled or exceeded chromium plating as a method for improving barrel performance.

Vapor-Deposited Coatings.

(U) Limited studies have been conducted on vapor deposition of these coatings of molybdenum and tungsten on steel barrels. These studies have been concerned primarily with attaining good adhesion, uniform thickness, and a suitable microstructure. Apparently, no firing tests have been conducted.

SUMMARY OF CURRENT PROGRAMS (U)

Rock Island Arsenal (U)

(U) Three projects are underway at Rock Island Arsenal, (Rock Island, Illinois). The projects involve liner materials, manufacturing methods, and liner treatment methods. Specifically, the following programs are being pursued:

(1) Explosive bonding of refractory-metal liners to steel.

(2) Coextrusion of refractory-metal liners with steel

(3) Ionitriding (glow-discharge nitriding) of steel.

Explosive Bonding (U)

(U) Explosive-bonding experiments are being conducted in cooperation with Frankford Arsenal. Preliminary work on this subject had been done in 1963.[11] In current work, the initial experiments consisted of bonding a strip of tantalum onto a strip of steel. Subsequently, 4-1/2-inch lengths of tantalum tubes were explosively bonded into smooth steel tubes. The third step was to bond a short, thin, tantalum-alloy (T111, Ta-8W-2Hf) tube into a prerifled steel tube, thereby forming the rifling on the tantalum liner at the time it is explosively bonded. Initial inspection of the resultant tantalum-alloy-lined steel tube revealed some cracks along the rifling, but this was thought to be the result of starting out with hard cold-worked tantalum.

(U) At this writing, steps are being taken to apply explosive bonding to longer tubes; no results are available.

(U) One of the additional advantages of explosively bonding the liner would be that in the process, gain-twist rifling would be incorporated. When the liner is introduced by swaging onto a solid mandrel, on the other hand, gain-twist rifling cannot be used because of the obvious problem of removing the mandrel.

Coextrusion (U)

(C) A firing test program is under way to evaluate coextruded tubing prepared in 1966 under a contract between Nuclear Metals Division of Whittaker Corporation and Springfield Armory. The preliminary coextrusion trials were made on AISI 4150 steel with a Ta-10W liner. The tubing as supplied had an OD of 1.43 inches, including a 17-mil-thick, low-carbon-steel extrusion jacket. The ID was 0.320 inch. A total of 54 pieces were supplied, ranging from 24 to 30.5 inches in length. In 47 of these the Ta-10W liner had a thickness of 25 mils; in the other 7 the liner thickness was 10 mils[12]. Final decisions had not been reached as to liner alloy and thickness, as of January 30, 1968. A tentative conclusion based on two extrusion trials and one firing test is that the liner was well-bonded to the steel barrel, and that somewhat less wear occurred at the origin of rifling in the composite barrel than in a chromium-plated steel standard barrel.

Ionitriding (U)

(U) The "Ionitriding" process is a name given to the Berghaus glow-discharge method of nitriding with nitrogen. Investigation of the process and its applicability to gun-barrel treatment is an in-house project at Rock Island Arsenal.

(C) In a firing test with M-61 barrels (six-barrel, 20mm Vulcan gun) the following were evaluated:

(A) 2 barrels: standard chromium-plated steel

(B) 2 barrels: Ionitrided steel

(C) 2 barrels: Ionitrided and chromium-plated steel.

(C) A 30,000-round firing program* was planned for the firing tests, that is, 5000 rounds per barrel. The tests were terminated before completing the entire 30,000 round schedule because of a "complete failure" (i.e., separation) of one of the "C" barrels. Prior to this event, after 21,000 rounds, one of the "B" nitrided barrels had been removed because of excessive velocity loss (>200 fpm). At that time both the "A" and the "C" barrels were in satisfactory condition.

(U) Thus, preliminary experiments seem to indicate that the ionitrided barrels offer no advantages over the standard chromium-plated barrels. Nevertheless, current plans call for continuing experimenting with the process in an attempt to improve it.

Army Mechanics and Materials Research Center[13] (U)

(U) At the time of this writing, AMMRC reports that they have a classified program with General Electric Company on gun barrel materials. Presumably this would be for the Minigun. Further details are being provided to DMIC, but they have not yet been received.

Eglin Air Force Base[14] (U)

(U) Eglin AFB reports that they have a program with General Motors Corporation on the vapor deposition ("vapor plating") of tungsten inside steel barrels. No details are available on the progress of the program.

(U) Presently under consideration by Eglin AFB are programs for coextrusion of Ta-10W-lined steel barrels. However, no contracts have been let.

IIT Research Institute[15] (U)

Exploratory investigation of the erosion of gun-barrel materials has been carried out in recent years by IIT Research Institute. Most of the work was supported by in-house funds.

(U) The apparatus used was described as a high-pressure vented bomb. In this device, the hot combustion gases from a 37 mm cartridge burning M2 double-base propellant escape through a replaceable nozzle. The nozzle is made of candidate barrel materials, and is subjected to the scrubbing action of the hot combustion gases and unburned powder, but not to contact with a projectile.

(U) The following insert materials were investigated:

- AISI 4150 steel
- Udimet 700
- D5 die steel
- AISI 4140 steel, with boronized coating
- High vanadium high-speed steel; 1840Z
- TZM molybdenum alloy
- TZC molybdenum alloy, boronized
- Waspaloy, boronized
- Ta-10W alloy, nitrided
- Ta-10W alloy, bare

Weight loss, hardness changes, and metallographic examination were used to evaluate the candidate materials.

(U) In addition to being used for materials evaluation, the IITRI device served as a means of investigating the effect of additives to the propellant.

(U) Preliminary evaluation suggests that TZM and TZC molybdenum alloys and Ta-10W are superior to other materials tested, in tests made both with and without a TiO_2 additive.

DISCUSSION AND CONCLUSIONS (U)

Limitations of Barrel-Material Studies (U)

(U) This brief review of the literature indicates that a wide variety of materials have been studied, and subsequently rejected, as candidates for improving the lifetime of small arms gun barrels. In some cases, the studies seem to have been very thorough and involved repeated attempts to optimize processing, design, and fabrication; furthermore, conclusions were based on a large number of carefully controlled firing tests, followed by an examination of the bore surface to identify the cause of failure. At the other extreme, a particular material may have been tested in only one barrel and the cause of failure may not have been established. This latter basis for disqualifying a material is clearly insufficient, but even the thorough testing may leave a number of questions unanswered. For example, in certain cases, the material under test exhibited a lifetime less than that shown by a Stellite 21 liner when tested under a particular firing schedule. However, it is entirely possible that under a different firing schedule the performance ratings would have been reversed. To be truly meaningful, these material evaluations should take into account several factors, including:

(1) Caliber of the weapon – the relative ratings of several barrel materials may not be the same for weapons of different caliber. This could be the result of different masses which influence heat transfer.

(2) Type of propellant – both composition and flame temperature may be important in determining the severity of attack of the bore. For example, it is known that Stellite 21 liners melt very quickly when used with a double-base propellant, but give reasonable lifetimes with a single-base propellant.[2] If a high flame-temperature propellant is used, it is likely that any refractory material, even though susceptible to brittle cracking, will outperform the lower melting Stellite 21.

(3) Firing Schedule – this is an extremely important factor in evaluating various materials. Relative ratings of various bore materials established for one firing schedule may be meaningless for a different firing schedule. For example, a high-melting-point bore material that is brittle at room temperature, might, if fired continuously until failure occurred, outperform a Stellite liner, which would rapidly exceed its melting point. On the other hand, firing in short bursts with intermediate cooling would probably result in cracking of the brittle material, whereas the Stellite would perform well.

(4) Composition and condition of the material being evaluated – this point should be obvious but it has received little attention in the various materials evaluations described in this report. The fact is that the strength, hardness, and ductility of materials, both at ambient temperature and at the temperatures encountered in the bore during firing, are highly dependent upon the chemical composition, and mechanical and thermal history of the material.

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*(C) The firing schedule was: 1200 rounds in four bursts of 300 rounds each (this takes about 3 sec), with 15 seconds between bursts, followed by complete cooling and examination.

(5) Attention to design and fabrication details – when a liner is used in a gun barrel, consideration must be given to its thermal-expansion coefficient in relation to that of the barrel material. Stellite, for example, expands more than gun steel, whereas molybdenum, and most other high-melting-point materials, expand less than steel. This allows the possibility that the steel will expand away from the liner, leaving it unsupported, and, thereby, require it to carry the entire pressure load. With regard to fabrication, it is important that a liner be attached to the barrel in such a way that no shifting of position can occur during firing.

(6) Reason for barrel failure in firing tests – barrels fail for various reasons, including wearing of the lands at the origin of rifling, cracking at the bore surface, melting of the bore, or bore erosion. In attempting to improve the performance of a particular type of material, it is important to know what led to failure. For example, if the bore surface melted, little benefit would be gained by a program aimed at improving the ductility.

DIRECTIONS FOR FUTURE RESEARCH(U)

(U) It seems clear that earlier work on gun-barrel materials failed to anticipate the high firing rates that modern gun systems are mechanically capable of providing. The logistic and tactical advantages of a longer lasting barrel in high-firing-rate guns are obvious, although economic considerations might preclude the application of certain materials capable of securing these advantages.

(U) Future research on gun-barrel materials, it would seem from an analysis of the past and current work, must emphasize the need for severe firing schedules. Many materials, previously discarded on the basis of cursory evidence, should be reexamined in the light of current needs, but the trend towards refractory-metal-alloy liners seems logical.

(U) The majority of past and current efforts to improve barrel performance have emphasized the use of liners in steel barrels. If maximum performance is to be achieved in modern gun systems, it may be necessary to find barrel materials superior to steel that will be capable of operating for long times at temperatures in excess of 1500 F without distortion. Nickel-base and cobalt-base superalloys and possibly even refractory-metal alloys are candidates for this application and should receive attention concurrently with liner-development programs.

(U) In many instances, the lack of manufacturing methods was a deterrent to the preparation of candidate barrels suitable for test firing. As an example, shrink fitting of certain combinations of liner and tube has not been developed to the extent needed to make long barrels(5). Clearly, manufacturing-methods development must accompany the materials-development programs if difficult-to-manufacture combinations are designed.

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(12) Letter from Saul Isserow, Nuclear Metals Division of Whittaker Corporation, January 2, 1968.

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(14) Personal Communication with Dale Davis, Eglin Air Force Base.

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APPENDIX A (U)

Tables of Contents for References (2), (3) and (4)

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APPENDIX B (U)

MILITARY SPECIFICATION STEEL, BARS AND BLANKS (UNDER 2 INCHES IN DIAMETER) FOR BARRELS OF SMALL ARMS WEAPONS (U)
MIL-S-11595D (MR), 3 January, 1966

(U) 1. SCOPE

(U) 1.1 Scope. This specification covers alloy steel bars and blanks under 2 inches in diameter for use in the manufacture of barrels for small arms weapons (see 6.1 and 6.3).

(U) 1.2 Classification.

(U) 1.2.1 Composition. Bars and blanks shall be furnished in the compositions listed in table I, as specified (see 6.2).

* (U) 1.2.2 Condition. Bars and blanks shall be furnished in the following conditions, as specified (see 6.2 and 6.3):

Bars (mill length).
- Hot rolled, as rolled.
- Hot rolled and annealed (see 6.6).
- Quenched and tempered.

Blanks and gun barrel bar lengths.
- As rolled or as forged.
- Cold formed blanks (spheroidize annealed before forming).
- Quenched and tempered.

(U) 2. APPLICABLE DOCUMENTS

(U) 2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

SPECIFICATIONS

Military	
MIL-M-12286	-Macroetch Test and Macrographs for Resulphurized Steel Bars, Billets and Blooms.

STANDARDS

Federal	
FED. STD. NO. 48	-Tolerances for Steel and Iron Wrought Products.
FED. STD. NO. 66	-Steel: Chemical Composition and Hardenability.
FED. TEST METHOD STD. NO. 151	-Metals; Test Methods.
Military	
MIL-STD-163	-Steel Mill Products Preparation for Shipment and Storage.
MIL-STD-430	-Macrograph Standards for Steel Bars, Billets, and Blooms.

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

* (U) 2.2 Other publications. The following document forms a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

Society of Automotive Engineers

AMS 2640	-Magnetic Particle Inspection.

(Application for copies should be addressed to the Society of Automotive Engineers, Inc., 485 Lexington Avenue, New York, New York 10017.)

(Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.)

(U) 3. REQUIREMENTS

(U) 3.1 Chemical composition. The chemical composition shall conform to the requirements shown in table I.

TABLE I. CHEMICAL COMPOSITION[1, 2, 3] (U)

	Composition		
	ORD 4150	ORD 4150 Resulfurized	Chrome-Moly-Vanadium
Element	Percent	Percent	Percent
Carbon	0.48 - 0.55	0.47 - 0.55	0.41 - 0.49
Manganese	0.75 - 1.00	0.70 - 1.00	0.60 - 0.90
Phosphorus	0.040	0.040	0.040
Sulfur	0.040	0.05 - 0.09	0.040
Silicon	0.20 - 0.35	0.20 - 0.35	0.20 - 0.35
Chromium	0.80 - 1.10	0.80 - 1.15	0.80 - 1.15
Molybdenum	0.25 - 0.25	0.15 - 0.25	0.30 - 0.40
Vanadium			0.20 - 0.30

[1] Chemical ranges and limits based on ladle analysis.

[2] Maximum except where indicated as a range.

[3] Steels containing elements not designated, in excess of the following amounts, shall be subject to rejection: copper 0.35 percent and aluminum 0.040 percent.

(U) 3.1.1 Ladle analysis. A certified ladle analysis of each heat or melt of steel (see 6.3) shall be furnished by the contractor showing the percentages of the elements present.

(U) 3.1.2 Check analysis. The chemical composition, as determined by check analysis (see 4.4.2 and 4.6.2.1), shall meet the applicable requirements specified in Federal Standard No. 66 except that check analysis for sulfur shall be required for ORD 4150 Resulfurized steel with an allowance of 0.01 percent under or over specification limits.

(U) 3.2 Quenched and tempered condition (see 1.2.2).

* (U) 3.2.1. Hardness. Bars and blanks specified in the quenched and tempered condition shall have a Brinell hardness of 277 to 331 when tested as specified in 4.4.3 and 4.6.2.2.

(U) 3.2.2 Heat-treatment. Heat-treatment shall consist of heating, quenching in circulating oil, and tempering to meet specified hardness and physical properties (see 6.5).

(U) 3.2.3 Stress relief. Unless otherwise specified, material which has been cold straightened after heat-treatment shall be stress relieved at a temperature not lower than 150° Fahrenheit (F.) below the final tempering temperature.

(U) 3.3 Impact resistance.

* (U) 3.3.1 Quenched and tempered condition. When bars or blanks are furnished in the quenched and tempered condition, test specimens from samples taken as specified in 4.4.4.3 shall have an average longitudinal impact value at a temperature of minus 40° F. of not less than 40 foot-pounds when tested as specified in 4.6.1.1 and 4.6.2.3. No individual value shall be less than 35 foot-pounds. When blanks are produced by processes which involve an upset forging operation in the cartridge chamber area, each test specimen taken from the chamber area shall have a longitudinal impact value at a temperature of minus 40° F. of not less than 15 foot-pounds. Specimens taken from the non-upset area (see 4.6.1.1.3(a)) shall meet the 40 foot-pound average and the 35 foot-pound individual requirements specified above.

* (U) 3.3.2 As rolled, as forged, cold formed, or annealed condition. When bars or blanks are furnished in any of the above conditions, test specimens from samples taken as specified in 4.4.4.2 and heat treated as specified in 4.6.1.1.2 to a Rockwell hardness of C 30 to C 35 (or the equivalent Brinell hardness as determined using the applicable conversion table contained in method 241 of Federal Test Method Standard No. 151) shall have an average longitudinal impact value at a temperature of minus 40° F. of not less than 40 foot-pounds when tested as specified in 4.6.1.1 and 4.6.2.3. No individual value shall be less than 35 foot-pounds. When blanks are produced by processes which involve an upset forging operation in the cartridge chamber area, each test specimen taken from the chamber area shall have a longitudinal impact value at a temperature of minus 40° F. of not less than 15 foot-pounds. Specimens taken from the non-upset area (see 4.6.1.1.3(a)) shall meet the 40 foot-pound average and the 35 foot-pound individual requirements specified above.

(U) 3.4 Macrostructure.

(U) 3.4.1 ORD 4150 and Chrome-Moly-Vanadium. The quality and cleanliness of the steel as indicated by the results of the macroetch test specified in 4.4.5, 4.6.1.2, and 4.6.2.4 shall be equal to or better than macrographs S-2, R-2, and C-2 for electric furnace process and S-3, C-3 and R-3 for open hearth process of MIL-STD-430.

(U) 3.4.2 ORD 4150 Resulfurized. The quality and cleanliness of the steel as indicated by the results of the macroetch test specified in 4.4.5, 4.6.1.2, and 4.6.2.4 shall be equal to or better than macrographs AS-B4 contained in MIL-M-12286 with all D defects unacceptable.

* (U) 3.5 Nonmetallic inclusions. The steel shall have a maximum average rating of 0.45 for both frequency and severity when tested as specified in 4.4.6, 4.6.1.3, and 4.6.2.5. No individual test specimen shall have a severity rating greater than 0.75.

(U) 3.6 Hardenability. The hardenability of the steel shall be not less than J52 (Rockwell C52) at 8/16 inch (one-half inch from the end of a standard Jominy or end-quench test specimen) when tested as specified in 4.4.7, 4.6.1.4, and 4.6.2.6.

* (U) 3.7 Forging practice. When forging operations are performed, process controls shall be subject to Government approval. Heating for forming shall be conducted using methods and equipment, including pyrometric controls, suitable for the purpose.

(U) 3.8 Dimensions and tolerances.

(U) 3.8.1 Blanks and forged bars. Blanks and forged bars (see 6.3) shall conform to the dimensions and tolerances specified in the contract or order (see 6.2).

* (U) 3.8.2 Hot rolled bars. Unless otherwise specified, hot rolled bars shall conform to the ordered dimensions and shall be within the tolerances shown in the following paragraphs of Federal Standard No. 48 (see 6.2).

Dimension	Paragraph
Diameter	161
Straightness	165

* (U) 3.9 Marking. Each bar or blank shall be suitably marked to identify the heat or melt. The marking medium shall not react objectionably with the surface of the steel during heat treatment. When specified, individual bars or blanks shall be identified as required in the invitation for bids or order (see 6.2).

(U) 3.10 Workmanship. Bars and blanks shall be sound, uniform in quality and condition, and commercially free of indications of overheating or burning, cracks, twists, seams, damaged ends, and other related defects injurious to the finished component (see 6.3).

(U) 4. QUALITY ASSURANCE PROVISIONS

(U) 4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

(U) 4.2 Classification of inspection. All examination and testing in this specification is classified as quality conformance inspection and shall be to determine conformance to the requirements of the specification to serve as a basis for acceptance of the material covered by this specification.

(U) 4.3 Lot. A lot shall consist of all material submitted for inspection at the same time, of the same heat or melt, same condition, same size, and, when heat-treated, shall be from the same furnace charge of a batch type furnace or shall be of the same heat treatment in a continuous furnace. Identification of each heat or melt shall be maintained throughout manufacture and inspection.

(U) 4.4 Sampling.

* (U) 4.4.1 For visual and dimensional examination. Unless otherwise specified in the contract or order, the contractor shall use his normal commercial sampling procedures.

(U) 4.4.2 For Government check analysis. When Government check analysis is performed, at least one sample shall be taken from each heat or melt. Each sample shall be composed of approximately 2 ounces of drillings or millings taken from bars or blanks in accordance with method 111 of Federal Test Method Standard No. 151. Samples shall be forwarded prepaid by the contractor to the designated testing agency (see 6.2).

(U) 4.4.3 For hardness testing. When bars or blanks are furnished in the quenched and tempered condition, the contractor shall take at random 10 samples from each 100 bars or fraction thereof. One defective sample shall cause rejection of the represented material.

(U) 4.4.4 For impact resistance testing.

• (U) 4.4.4.1 Quenched and tempered condition. Bars or blanks shall be taken from each heat or melt in accordance with the applicable schedule contained in table II. Sampling shall be performed in alphabetical sequence as specified in table II, and tests for each schedule must be satisfactorily completed prior to undertaking the next schedule. Sampling will revert to schedule A when any of the following occurs:

(a) Failure of sample specimens to meet impact resistance requirements (see 3.3.1).
(b) Modification of the heat treat process.
(c) Utilization of new heat-treat equipment.
(d) Samples are taken from new heat or melt.
(e) When continuous furnace is restarted after shutdown.

TABLE II. SAMPLING FOR IMPACT RESISTANCE TESTING (U)

Schedule	Batch Furnace	Continuous Furnace
A	One bar or blank from each quench lot for three consecutive quench lots from each heat treat furnace used	One bar or blank at start of operation. Three bars or blanks from each 1,000 bars or blanks or each 8 hours of operation, whichever occurs first. Samples shall be taken at beginning, middle, and end of run. Ten consecutive satisfactory tests representing runs of 1,000 bars or blanks or 8 hours operation shall be obtained before proceeding to schedule B
B	One bar or blank from every 4 quench lots or each day's production, whichever occurs first, from each heat treat furnace used for 20 consecutive samples.	One bar or blank from each 1,000 bars or blanks or each 8 hours of operation, whichever occurs first.
C	One bar or blank from each week's production from each heat-treat furnace used	

• (U) 4.4.4.2 As rolled, as forged, cold formed, or annealed condition. One sample shall be taken from material representing the top and bottom of the first and last usable ingots of the heat or melt (four samples per heat or melt). Blooms or billets may be forged to bar or blank diameter for use as samples for this testing. At the option of the Government, random sampling may be used by taking at least 1 bar or blank for each 10,000 pounds of material, or fraction thereof. In any case the sample to be tested shall be of the diameter specified in the contract or order (see 6.2).

(U) 4.4.5 For macroetch testing. Full cross-section samples shall be taken after discard, from billets representing the top and bottom of the first, middle, and last usable ingots of each heat or melt. At the option of the Government, random sampling may be used by taking a full cross-section sample from at least 1 billet in each 10,000 pounds of material, or fraction thereof. In the absence of billet tests, 10 bars shall be taken from each lot.

• (U) 4.4.6 For nonmetallic inclusion testing. A sample shall be taken from bars and blanks representing the top and bottom of the first and last usable ingots from heats or melts having not over 10 ingots or more than 30 tons, or from portions of heats or melts within these limits; and from the top and bottom of the first, middle, and last usable ingots of heats or melts having more than 10 ingots or over 30 tons. Blooms and billets may be forged to finished bar or blank size for use as samples for this testing. At the option of the Government, random sampling may be used by taking a sample of 10 bars or blanks from each lot. When specified in the contract or order (see 6.2), the contractor shall submit to the procuring agency, prior to or not later than delivery of the product of the heat or melt, test samples from the same bar or blanks from which the contractor's test samples were taken. These samples shall be approximately 14 inches long.

• (U) 4.4.7 For hardenability testing. At least one sample shall be taken from material representing the top and bottom of the first and last usable ingots in the heat or melt (four samples per heat or melt).

(U) 4.5 Examination.

• (U) 4.5.1 Forging practice. Periodic surveillance of forging practice shall be conducted to assure compliance with the requirements of 3.7. The Government representative shall have access to pyrometers and recording instruments and to their records. The accuracy of the pyrometers and sensing devices shall be checked by the contractor using suitable calibrating equipment whenever requested by the Government representative.

(U) 4.5.2 Heat treatment and stress relief. Periodic process surveillance shall be conducted to assure compliance with the heat treatment (see 3.2.2) and stress relief (see 3.2.3) requirements.

(U) 4.5.3 Dimensional, marking, and workmanship. Bars and blanks shall be inspected by any suitable method acceptable to the Government to assure compliance with dimensional (see 3.8), marking (see 3.9), and workmanship (see 3.10) requirements.

(U) 4.5.4 Preparation for shipment. Examination of the preservation, packaging, packing, and marking for shipment shall be made for conformance to the requirements of section 5.

(U) 4.6 Tests.

(U) 4.6.1 Test specimens.

(U) 4.6.1.1 Impact resistance.

• (U) 4.6.1.1.1 Quenched and tempered condition. At least two V-notch Charpy impact specimens shall be taken (see 4.6.1.1.3) from each sample bar or blank (see 4.4.4.1) and prepared in accordance with method 221 of Federal Test Method Standard No. 151. When blanks are produced by processes which involve an upset forging operation in the chamber area, at least two additional specimens shall be taken as specified in 4.6.1.1.3(a), and prepared as specified above.

• (U) 4.6.1.1.2 As rolled, as forged, cold formed, or annealed condition. Heat-treatment shall be performed on each bar or blank, taken in accordance with 4.4.4.2, or on cylindrical test coupons taken from a sample bar or from the chamber area of a sample blank. Heat-treatment shall consist of austenitizing, oil quenching, and tempering, in accordance with table IV, to the hardness range specified in 3.3.2 (see 6.5). Heat-treatment should be conducted in a manner to produce a microstructure of tempered martensite in the material. Preliminary normalizing may be used. After heat-treatment, at least two V-notch Charpy impact specimens shall be taken (see 4.6.1.1.3) from each sample bar, blank, or test coupon, and prepared in accordance with method 221 of Federal Test Method Standard No. 151. When blanks are produced by processes which involve an upset forging operation in the chamber area, at least two additional specimens shall be taken as specified in 4.6.1.1.3(a), and prepared as specified above. Hardness readings to determine compliance with 3.3.2 shall be taken in accordance with method 242 or 243, as applicable, of Federal Test Method Standard No. 151 on the notched face of the hardened test specimen within one-fourth inch of the centerline of the notch.

• (U) 4.6.1.1.3 Location from which test specimens shall be taken. Unless otherwise specified, Charpy impact test specimens shall be taken from sample bars, blanks, or test coupons, as follows:

(a) Blanks. From the chamber area, at least one major chamber diameter away from the chamber end. When blanks are produced by processes which involve an upset forging operation in the chamber area, the additional specimens shall be taken from a non-upset area beginning between 2 to 3 inches forward of the upset section.
(b) Bars. From an area at least one bar diameter away from the bar end.
(c) Test coupons. From an area at least one cylinder diameter away from the coupon end.

(U) 4.6.1.2 Macrostructure. Specimens shall be prepared in accordance with method 321 of Federal Test Method Standard No. 151.

(U) 4.6.1.3 Nonmetallic inclusions.

• (U) 4.6.1.3.1 Type of specimen. Unless otherwise specified, testing for nonmetallic inclusions shall be conducted using the step-down specimen. When specified in the contract or order (see 6.2), a straight cylindrical specimen may be used in lieu of the step-down specimen.

(U) 4.6.1.3.1.1 Step-down specimen. The step-down specimen shall be generated in equal length circumferential steps as follows:

Bar or blank diameter	Step length	Step diameter				
Inches	Inches	1	2	3	4	5
over 0.500 to 0.750 incl.	2.500	D	2/3D			
over 0.750 to 1.000 incl.	1.665	D	3/4D	1/2D		
over 1.000 to 1.500 incl.	1.250	D	4/5D	3/5D	2/5D	
over 1.500 to 1.990 incl.	1.000	D	4/5D	3/5D	2/5D	1/5D

D = original diameter minus machining stock removed (see 4.6.1.3.2).

• (U) 4.6.1.3.1.2 Straight cylindrical specimen. The specimen shall be machined in accordance with the machining allowance specified in 4.6.1.3.2, to a straight cylindrical specimen 5 inches ± 1/16 inch in length.

(U) 4.6.1.3.2 Machining allowance.

Diameter Inches	Minimum stock removal[1] Inch (measured on radius)
over 0.500 to 0.750 incl.	0.045
over 0.750 to 1.000 incl.	0.060
over 1.000 to 1.500 incl.	0.075
over 1.500 to 1.990 incl.	0.090

[1] Allow 0.010 inch for finish machining after heat treatment.

• (U) 4.6.1.3.3 Heat treatment. Rough machined specimens shall be hardened by suitably austenitizing, quenching, and tempering to produce a hardness not lower than Brinell 250.

(U) 4.6.1.3.4 Surface finish. The finish machined surface of the test specimen shall not exceed a roughness height rating of 40 microinches. The ends shall be finished to provide good electrical contact.

(U) 4.6.1.4 Hardenability. Specimens shall be prepared in accordance with method 711 of Federal Test Method Standard No. 151.

(U) 4.6.2 Test methods.

(U) 4.6.2.1 Chemical analysis. Chemical analysis of the samples taken in accordance with 4.4.2 shall be conducted in accordance with method 111 or 112 of Federal Test Method Standard No. 151. In cases of dispute, referee analysis shall be in accordance with method 111.

(U) 4.6.2.2 Hardness. Hardness readings shall be taken in accordance with method 242 of Federal Test Method Standard No. 151 on the exterior of the test bars and blanks.

(U) 4.6.2.3 Impact resistance. Charpy impact test shall be conducted in accordance with method 221 of Federal Test Method Standard No. 151. The temperature of the test specimen at the time of fracture shall be minus 40° ± 2° F.

(U) 4.6.2.4 Macrostructure. The macroetch test shall be conducted in accordance with method 321 of Federal Test Method Standard No. 151.

(U) 4.6.2.5 Nonmetallic inclusions. The nonmetallic inclusion content shall be determined by the method specified below.

• (U) 4.6.2.5.1 Testing. Testing shall be by the wet magnetic particle method specified in Aerospace Material Specification (AMS) 2640 using circular magnetization with a magnetizing current of 900 to 1,100 amperes per inch of diameter. Direct current shall be used for magnetizing. When the step-down specimen is used, the smallest step shall be magnetized and inspected first, the next larger steps shall be magnetized and inspected in succession. Inclusions one-eighth inch or less in length shall not be counted.

(U) 4.6.2.5.2 Results. The frequency and severity of nonmetallic inclusions shall be determined as shown below.

(U) 4.6.2.5.2.1 Frequency.

(a) Total the number of indications for each specimen.
(b) Divide the total number of indications per specimen by the surface area of the specimen in square inches. This value is the frequency rating of the specimen.
(c) Total the frequency ratings of the specimens.
(d) Divide the total frequency ratings by the number of specimens. This value is the average frequency rating.

(U) 4.6.2.5.2.2 Severity.

(a) The length of each indication is recorded.
(b) Total the number of indications for each size interval shown in table III.
(c) Multiply the total number per size interval by the severity factor of table III.
(d) Total the products obtained in (c) for each specimen.
(e) Divide the product total by the surface area of the specimen in square inches. This value is the severity rating for the specimen.
(f) Total the severity ratings of the specimens.
(g) Divide the total severity ratings by the number of specimens. This value is the average severity rating.

TABLE III. SEVERITY OF NONMETALLIC INCLUSIONS (U)

Indication length[1] Inch	Severity factor
over 1/8 to 1/4 incl.	1
over 1/4 to 1/2 incl.	2
over 1/2 to 3/4 incl.	4
over 3/4 to 1 incl.	8
over 1	16

[1] When the step-down specimen is used, an inclusion extending the entire length of a step shall be considered to be longer than 1 inch and shall be assigned a weight of 16.

(U) 4.6.2.6 Hardenability. The hardenability test shall be conducted in accordance with method 711 of Federal Test Method Standard No. 151 except that the austenitizing temperature shall be as specified in table IV.

TABLE IV. HEAT TREATMENT PROCEDURE

Composition	Normalizing temperature (°F.)	Austenitizing temperature (°F.)	Approximate tempering temperature (°F.)
Chrome-Moly-Vanadium	1675 ± 25	1600 ± 25	1200
ORD 4150 and ORD 4150 Resulfurized	—	1575 ± 25	1150

(U) 4.7 Rejection.

(U) 4.7.1 Examination. Individual bars or blanks not meeting the requirements of this specification shall be rejected. When sampling inspection is used, the represented lot shall be rejected when the number of rejected sample units equals or exceeds the rejection number specified.

(U) 4.7.2 Tests. Failure to comply with any of the test requirements of this specification shall be cause for rejection of the represented material.

(U) 4.8 Retests. Retests shall be permitted in accordance with Federal Test Method Standard No. 151.

* (U) 4.9 Calibration of impact test machines. Charpy impact test machines shall be calibrated under the surveillance of the Government representative within a period not exceeding 1 year previous to use, using test samples prepared by U.S. Army Materials Research Agency (see 6.4).

(U) 5. PREPARATION FOR DELIVERY

(U) 5.1 Preservation and packaging.

(U) 5.1.1 Level A. Preservation and packaging of bars and blanks shall be in accordance with MIL-STD-163.

(U) 5.1.2 Level C. Preservation and packaging of bars and blanks shall be in accordance with standard commercial practice.

(U) 5.2 Packing.

(U) 5.2.1 Level A. Packing of bars and blanks shall be in accordance with MIL-STD-163.

(U) 5.2.2 Level C. Packing of bars and blanks shall be in accordance with standard commercial practice adequate to insure carrier acceptance and safe delivery at the lowest rate. Shipments shall comply with the requirements of the regulations applicable to the mode of transportation.

(U) 5.3 Marking. In addition to any special markings required by the contract or order, shipments shall be marked in accordance with MIL-STD-163 (see 6.2). The heat or melt identification shall be required as part of the basic marking.

(U) 6. NOTES

* (U) 6.1 Intended use.

(U) 6.1.1 Steel covered by this specification is intended for use in the manufacture of gun barrels requiring deep hole drilling and rifling operations.

(U) 6.1.2 The scope of this specification does not limit the size of bars and blanks purchased in the unheat-treated condition, provided that material will be under 2 inches in diameter when heat-treatment is performed.

(U) 6.2 Ordering data. Procurement documents should specify the following:

(a) Title, number, and date of this specification.
(b) Whether bars or blanks are required.
(c) Composition and condition required (see 1.2).
(d) Size required (see 3.8).
(e) When sampling other than contractor's normal sampling procedure is specified (see 4.4.1).
(f) Shipping instructions for Government check analysis sample (see 4.4.2).
(g) Selection of applicable levels of preservation, packaging, and packing (see section 5).
(h) When special marking is required (see 5.3).
(i) Certification requirements.
(j) Special marking on bars or blanks (see 3.9).
(k) Whether nonmetallic inclusion test samples are required by the procuring agency (see 4.4.6).
(l) Diameter of sample to be tested for impact resistance (see 4.4.4.2).
(m) When straight cylindrical specimen is specified for nonmetallic inclusions testing (see 4.6.1.3.1).

* (U) 6.3 Definitions. Listed below are definitions of some of the special terms used in this specification.

As forged - As forged, upset, or extruded.
Blank - A partially formed gun barrel requiring machining or some other operations to produce a finished barrel.
Crack - Separation of material visually evidenced by a fine irregular line.
Forged bar - A hot rolled bar that has had any subsequent working (see "as forged").
Gun barrel bar length - Length of finished barrel plus allowance for machining.
Heat - Metallic output of one charge of an open hearth furnace (see "melt").
Melt - Metallic output of one charge of an electric furnace ("heat" and "melt" are often used interchangeably).
Mill length - Length of bar produced by steel mill. Mill length bars are usually furnished in multiple gun barrel bar lengths plus allowance for loss of material in cutting.
Seam - An unwelded lap or fold on the surface of metal usually produced during rolling or forging. May appear to be a crack.
Twist - A distortion caused by the rotation of the ends of a bar in opposite directions.

* (U) 6.4 Test samples for calibration of Charpy impact test machines may be obtained from U. S. Army Materials Research Agency, Watertown, Massachusetts 02172, through the applicable Procurement District Office (see 4.9).

(U) 6.5 Heat-treatments indicated in table IV are for guidance.

(U) 6.5.1 Minimum holding time for each heat treating operation should be 1 hour at heat for each inch of thickness at the maximum effective cross-section.

* (U) 6.6 For ease in cutting into barrel lengths, hot rolled mill length bars should be ordered in an annealed condition to a maximum Brinell hardness of 250.

(U) 6.7 The margins of this specification are marked with an asterisk to indicate where changes (additions, modifications, corrections, deletions) from the previous issue were made. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations and relationship to the previous issue.

Custodian:
Army - MR

Preparing activity:
Army - MR

Review activity
Army - MR

Project No. 9510-A024

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Battelle Memorial Institute
Defense Metals Information Center
505 King Avenue, Columbus, Ohio 43201

2a. REPORT SECURITY CLASSIFICATION

Confidential

2b. GROUP

3. REPORT TITLE

Materials for Small-Arms Gun Barrels (U)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

DMIC Report S-20

5. AUTHOR(S) (Last name, first name, initial)

Marschall, C. W. and Wagner, H. J.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
April 4, 1968	21	15

8a. CONTRACT OR GRANT NO.

F33615-68-C-1325

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

DMIC Report S-20

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

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11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

U.S. Air Force Materials Laboratory
Wright-Patterson Air Force Base, Ohio

13. ABSTRACT

(U) At the request of the U.S. Air Force, a survey was conducted by the Defense Metals Information Center on materials for small-arms gun barrels (up to approximately 30-mm-bore diameter). Particular emphasis was given to materials for weapons designed for high rates of fire.

(U) The Report discusses some of the factors which affect the choice of barrel materials, such as the pressure, projectile velocity, and barrel temperatures. Research on new barrel materials, liners, and surface treatments through 1960 is summarized. Current research at both Government and private facilities is discussed.

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Gun Barrels						
Barrel Liners						
Erosion						
Surface Treatments						
Nitriding						
Chromizing						
Plating						
Explosive Bonding						
Specifications						
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DEPARTMENT OF THE AIR FORCE
AIR FORCE RESEARCH LABORATORY
WRIGHT-PATTERSON AIR FORCE BASE OHIO 45433

23 January 2004

MEMORANDUM FOR: Defense Technical Information Center /OCQ
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FROM: AFRL/WSCL (STINFO)
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1. Please change subject report as follows:

   Change the distribution to distribution statement A.

2. Point of contact is the undersigned at DSN 785-5766

Sharon L. Serzan

SHARON L. SERZAN, STINFO Officer
Technical Information Office

cc: Technical Reports Vault